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QUANTITATIVE EVALUATION OF ROUTE ALLOCATION SOLUTIONS AT LARGE-SCALE PASSENGER STATIONS

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Abstract

Routing trains within passenger stations in major cities is a common scheduling problem for railway operation. Various studies have been undertaken to derive and formulate solutions to this route allocation problem (RAP) which is particularly evident in mainland China nowadays because of the growing traffic demand and limited station capacity. A reasonable solution must be selected from a set of available RAP solutions attained in the planning stage to facilitate station operation. The selection is however based on the experience of the operators only and objective evaluation of the solutions is rarely addressed. In order to maximise the utilisation of station capacity while maintaining service quality and allowing for service disturbance, quantitative evaluation of RAP solutions is highly desirable. In this study, quantitative evaluation of RAP solutions is proposed and it is enabled by a set of indices covering infrastructure utilisation, buffer times and delay propagation. The proposed evaluation is carried out on a number of RAP solutions at a real-life busy railway station in mainland China and the results highlight the effectiveness of the indices in pinpointing the strengths and weaknesses of the solutions. This study provides the necessary platform to improve the RAP solution in planning and to allow train re-routing upon service disturbances.

1 Introduction

Routing trains in railway stations is a common problem for railway scheduling and operation, and various approaches are proposed to solve the problem in previous studies [1, 4, 6]. This route allocation problem (RAP) is to assign conflict-free inbound/outbound routes and platforms to trains at stations under the given service timetables and station layouts. Different route allocation solutions (RAS) can be obtained from various methods. While they are all feasible, there is no proper evaluation on these solutions. Railway planners must select one solution from a set of given RAS in order to direct the daily station operations; therefore a quantitative evaluation of RAS is needed to facilitate the selection.

For mainline railways in China, the passenger services are in rapid development and the total length of track throughout the country adds up to 120,000km. A large number of large-scale passenger stations are located along the lines and the high traffic volume turns these stations into very busy traffic hubs. Therefore, routing trains through these stations and the reasonable utilisation of the infrastructure at the stations is an important issue in China now.

In order to enable proper RAS evaluation for the planning and operation of the busy stations in China, the paper puts forward a set of quantitative indicators covering infrastructure utilisation and buffer times. They reflect the infrastructure workload and delay-tolerance of the station operation. A case study based on a large-scale passenger station in China highlights the advantages and limitations of the RASs through the proposed indices. The needs and requirements of quantitative evaluation of RASs are then discussed.

2 RAS evaluation

In China, mainline passenger train services are usually classified according to the train speeds and travelling distances. In general, there are high-speed, express and ordinary train services, in descending order of ticket price and thus priority. As a usual practice, the most convenient platforms for passenger entry/exits and transfers over lines at stations are allocated to services of higher priority, sometimes even exclusively. On the other hand, services of lower priority have to share certain platforms. A RAS should be able to reflect the observation of the priorities given to different services.

From the viewpoint of operation reliability, infrastructure workload balance is another objective of routing trains through stations [5]. For example, there may be a serious traffic bottleneck if the usage of a switch is particularly high, i.e. a large number of trains are scheduled to pass through the switch and the neighbouring track sections. If such imbalance is to be identified and resolved, the system reliability can be enhanced and traffic congestion is alleviated as a result. In other words, infrastructure utilisation within the station is an essential reference for the station management to determine the appropriate RAS to meet the demands of the timetabled services.

Even though a feasible RAS implies that each train is to arrive at and depart from the station in adherence to the given timetables through the allocated inbound and outbound routes, disturbances are inevitable in real-life operations and buffer times embedded in the RAS is the means to absorb delays. Indeed, the buffer times and their distribution within the RAS manifest the capability of delay-tolerance of the RASs. For a number of given RASs, the corresponding sets of buffer times are generally different and thus the RASs react differently to the same disturbance. It is therefore necessary to include the comparison of delay-tolerance as one of the criteria for RAS evaluation. Buffer times for railway timetables evaluation is also discussed in previous works [2].

From the discussions above, the following evaluation indices are proposed for the evaluation of RASs at the main stations in China mainline railways.

2.1 Platform preference

K is the set of platforms of the station and $p_{t,k}$ shows the preference of the train $t \in T$ for the platform $k \in K$ where T is the set of trains. $p_{t,k}$ are valued based on experience and the maximum value is one which means that the platform k is the best for the train t to stay, while the minimum value is zero which indicates that k is the worst for t to dwell or t cannot be routed to k. The binary variable $x_{t,k} = 1$ means that t selects k to dwell and $x_{t,k} = 0$ indicates otherwise. The index p_T is expressed in Eqn (1) and it ranges from 0 to 1.

$$p_T = \sum_{t \in T} \sum_{k \in K} x_{t,k} p_{t,k} \Big/ |T| \qquad (1)$$

This index shows the level of satisfaction of routing trains to the most preferable platforms. Each train has a certain preference for the platforms because of the travelling direction and the priority of the train services, as well as the possible services connection and transfers. A RAS is expected to satisfy the requirements of all trains on the preference of the platforms; however it is not always possible due to station capacity constraints. In practice, some trains have to be routed to less-preferred platforms. This index provides an numerical overall summary of the fulfilment of the platform preference in the station operation.

2.2 Platform track utilisation

P is the set of platform tracks within the station area , T_p is the set of trains which are to be routed to the platform track p, and the time duration for t to occupy p is denoted by $Time(t, p)$. The utilisation of p is obtained as below.

$$\alpha_p = \sum_{t \in T_p} Time(t, p) \Big/ d_T \qquad (2)$$

d_T is the time duration of the input timetable. The minimum value of α_p is zero which means that no trains are routed to p, and its maximum is one which indicates that all trains are routed to p and there are no buffer times between any two trains. Indeed, the value of α_p is always less than one because a certain amount of buffer times are normally inserted between train services during the formulation of the train service timetables.

2.3 Buffer times introduced and minimum buffer time

Buffer time is the temporal distance between trains' arrival and departure events, and there is no buffer time between two events if the routes to serve them are parallel. The example below shows the buffer times between train services at a simple station layout.

Fig.1 shows a simple station layout with 6 tracks, 8 switches and 10 track sections. If there is a RAS including three trains t_1, t_2 and t_3 and the arrival route of t_1 is $\langle g_1, g_2, g_6 \rangle$, while the departure routes of t_2 and t_3 are $\langle g_2, g_1, g_3 \rangle$ and $\langle g_4, g_3 \rangle$ respectively, the time events of the three trains going through the routes events are illustrated in Fig.2 and they are denoted by the corresponding rectangles. The track sections and time are represented on the vertical and horizontal directions respectively.

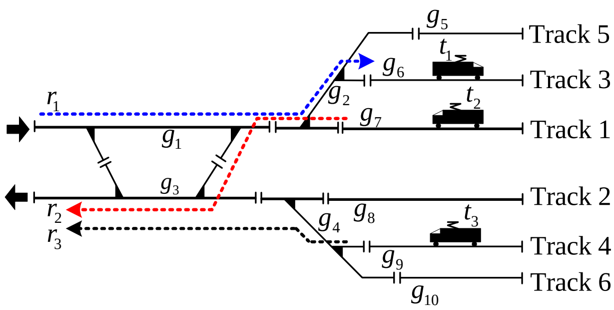

Fig.1 A simple station layout with three trains

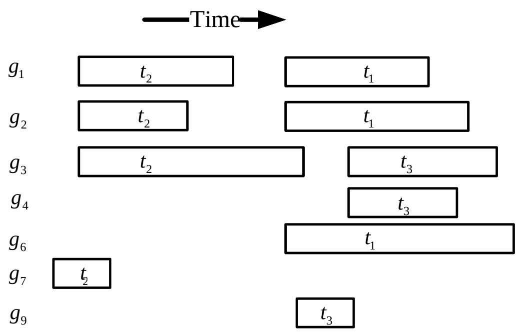

Fig.2 Time blocks on the track sections by the three trains

From Fig. 2, the buffer time between t_1 and t_2 is the gap between the two rectangles at g_1 while the buffer time between t_2 and t_3 is the corresponding gap at g_3. The time spans of the rectangles, i.e. train travelling time within track sections, can be obtained by a simple train movement simulator [3] and the buffer times, i.e. time-gaps between rectangles, are attained accordingly.

When delay arises, it does not propagate from one train to another if the two trains do not share the same set of track section (even when there is no buffer time between them), such as t_1 and t_3 in Fig.1. However, the delay propagation occurs if the disturbance is larger than the buffer time between two trains. Hence, the very existence of the buffer times indicates the potential congestion or even conflicts. The number of buffer times required in the RAS thus implies the overall vulnerability to delay and service disturbance.

To enable the buffer times to be considered as RAS evaluation criteria, the following indices are proposed. The binary variable $x_{i,j}=1$ means that there is a buffer time between trains i and j, and $x_{i,j}=0$ denotes that there is no buffer time. It is worth noting that buffer time is a directional parameter and $x_{i,j}=1$ implies that a delay may propagate from the train i to j, not from j to i. The number of buffer times embedded in a RAS is expressed as follows.

$$b_T=\sum_{i\in T}\sum_{j\in T}x_{i,j},\ \text{for all } i,j\in T, i\neq j \qquad (3)$$

The minimum buffer time denote the minimum value among all embedded buffer times. The buffer time is $b_{i,j}$ under the condition of $x_{i,j}=1$ and the minimum buffer time is given below.

$$b_{T,\min}=\min\{b_{i,j}\},\ \text{for all } i,j\in T, i\neq j\wedge x_{i,j}=1 \qquad (4)$$

The value of this index gives the maximum disturbance that the RAS is able to tolerate before delay propagation arises. In other words, a RAS with a smaller value of minimum buffer time is more susceptible to disturbances.

3 Case study

In order to illustrate the application of the proposed evaluation indices and their effectiveness on identifying the strengths and weaknesses of the RAS, a real-life train station at the heart of the most-populated city at the Southern China, Guangzhou, as shown in Fig. 3; and a one-hour timetable are employed as the case study. There are 542 and 480 entrance/exit routes at the station which serves both passenger and freight traffic from 7 directions. There are a total of 15 platforms, 28 platform tracks and 126 switches at the stations. In addition, there are a considerable number of shunting movements which are not included in the train services timetable. Therefore, the operation of the station is very busy.

Fig. 4 shows a selected section of the station, which has been used in this case study. The encircled numbers denote the track sections and they form the inbound and outbound routes. There are 46 track sections and 161 inbound/outbound routes while 11 platforms, denoted by solid blocks, are available. The numbers on the left-hand side of Fig. 4 indicate the platform tracks. It can be seen that the two tracks 1 and 3 share the same platform, so do tracks 5 and 7. For a train entering the station from direction A, even though tracks 1 and 3 share the same platform, the train may prefer track 1 as the corresponding route consists of less number of track sections.

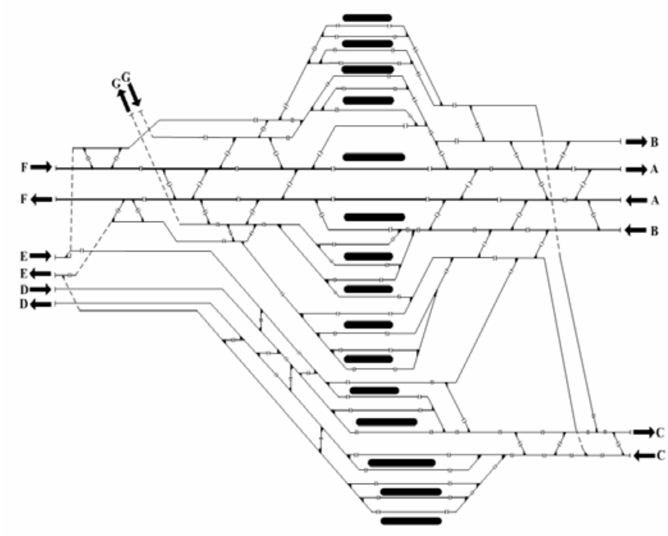

Fig. 3 Guangzhou station layout

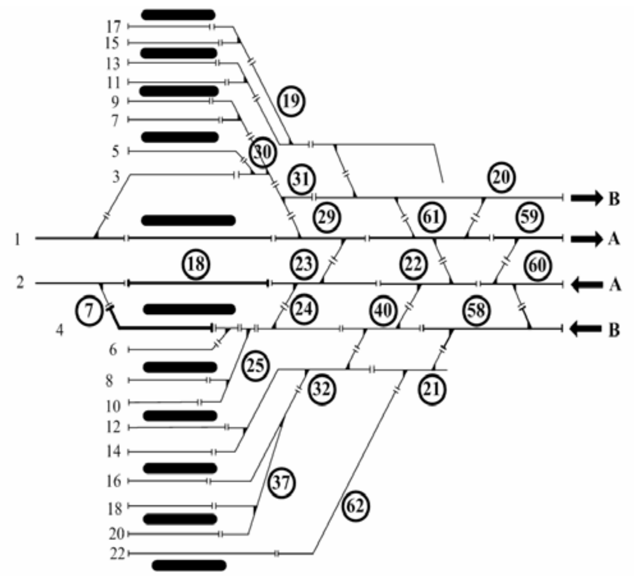

Fig. 4 Selected section of the Guangzhou station

Two possible RASs are listed in Table 1 and they both cover the operation of an off-peak hour, in which 8 trains are to be routed. The scheduled arrival and departure times are also given in Table 1 and the preferences for platforms of the train services are listed in Table 2. Indeed, each train may have its own preference for platforms, and as the trains' levels and travelling directions in the case study are the same, so their preferences for platforms are also the same. While Table 1 gives the codes of the inbound and outbound routes adopted in the RASs, Table 3 lists the sequences of the track sections involved in the corresponding routes. The track sections of the platforms are not included here.

Train ID	Arrival Time	Departure Time	RAS1			RAS2		
			Platform track	Inbound route	Outbound route	Platform track	Inbound route	Outbound route
0	6:58:00	7:00:00	1	947	25	3	971	101
1	7:04:00	7:06:00	2	945	28	1	947	25
2	7:10:00	7:12:00	1	947	25	5	955	182
3	7:18:00	7:22:00	1	947	25	7	970	193
4	7:24:00	7:28:00	2	945	28	11	983	217
5	7:30:00	7:34:00	1	947	25	3	975	46
6	7:46:00	7:48:00	1	947	25	13	969	250
7	7:52:00	7:54:00	2	945	27	1	947	25

Table 1 Two possible RASs under the given station layout and timetable

Platform tracks	1	2	3	4	5	6	7	8	9	others
Preferences	1	0.9	0.8	0.7	0.6	0.5	0.4	0.2	0.1	0

Table 2 Platform preference

	ID	Track sections
Inbound routes	947	<58, 60, 22, 61, 29>
	945	<58, 60, 22, 23>
	971	<58, 60, 22, 61, 20, 31>
	955	<58, 60, 22, 61, 20, 31, 30>
	970	<58, 60, 22, 61, 20, 31, 30>
	983	<58, 60, 22, 61, 20, 21, 19>
	975	<58, 60, 22, 61, 20, 31, 30>
	969	<58, 60, 22, 61, 20, 21, 19>
Outbound routes	25	<29, 61, 59>
	27	<23, 29, 61, 59>
	28	<23, 22, 60, 59>
	46	<30, 31, 29, 61, 59>
	101	<30, 31, 20, 61, 59>
	182	<30, 31, 29, 61, 59>
	193	<30, 31, 29, 61, 59>
	217	<19, 21, 20, 61, 59>
	250	<19, 21, 20, 61, 59>

Table 3 Track sections of the inbound/outbound routes

The evaluation indices of the two RASs are computed and then listed in Table 4. The platform preferences of two RASs are 0.96 and 0.58 respectively, which indicates that the trains in RAS1 are assigned to the platforms of higher preference. Table 1 also verifies the same results as the trains in RAS1 are routed to track 1 and 2 which are the most preferred platform tracks. On the other hand, only two trains are routed onto the track 1 in RAS2.

	Platform preference	Number of embedded buffer times	Minimum buffer time (seconds)
RAS1	0.96	26	17
RAS2	0.58	28	188

Table 4 Evaluation of the two RASs

There is only a slight difference between the numbers of embedded buffer times in the two RASs, implying that the numbers of potential conflicts with the adoption of two RASs are roughly the same. However, the minimum buffer time in RAS1 is only 17 seconds and that in RAS2 is 188 seconds. RAS1 is therefore overwhelmingly more susceptible to delays than RAS2.

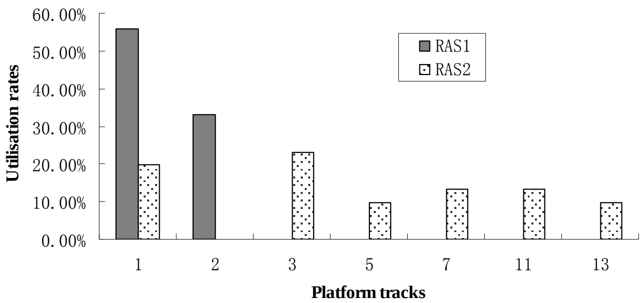

Fig. 5 Platform tracks utilisation rates of two RASs

In addition, track 1 and track 3 are the platform tracks with the highest utilisation in the two RASs. Fig.5 shows the platform track utilisation and the maximum platform track utilisation rates are 55.97% and 23.06% for the two RASs respectively. The workload balance of RAS2 is thus better than that of RAS 1.

4 Conclusions

A number of evaluation indices for the quantitative evaluation of route allocation solutions have been proposed in this study. The indices are applied at a section of the Guangzhou station in China and two RASs are evaluated for a one-hour timetable. The case study demonstrates the effectiveness of the evaluation indices and the RASs are given comparisons on various aspects with clear outright results.

This study provides the first step for further works on comprehensive quantitative evaluations of RASs and it also explores the investigation of dynamic re-allocation of routes upon disturbances.

Acknowledgements

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